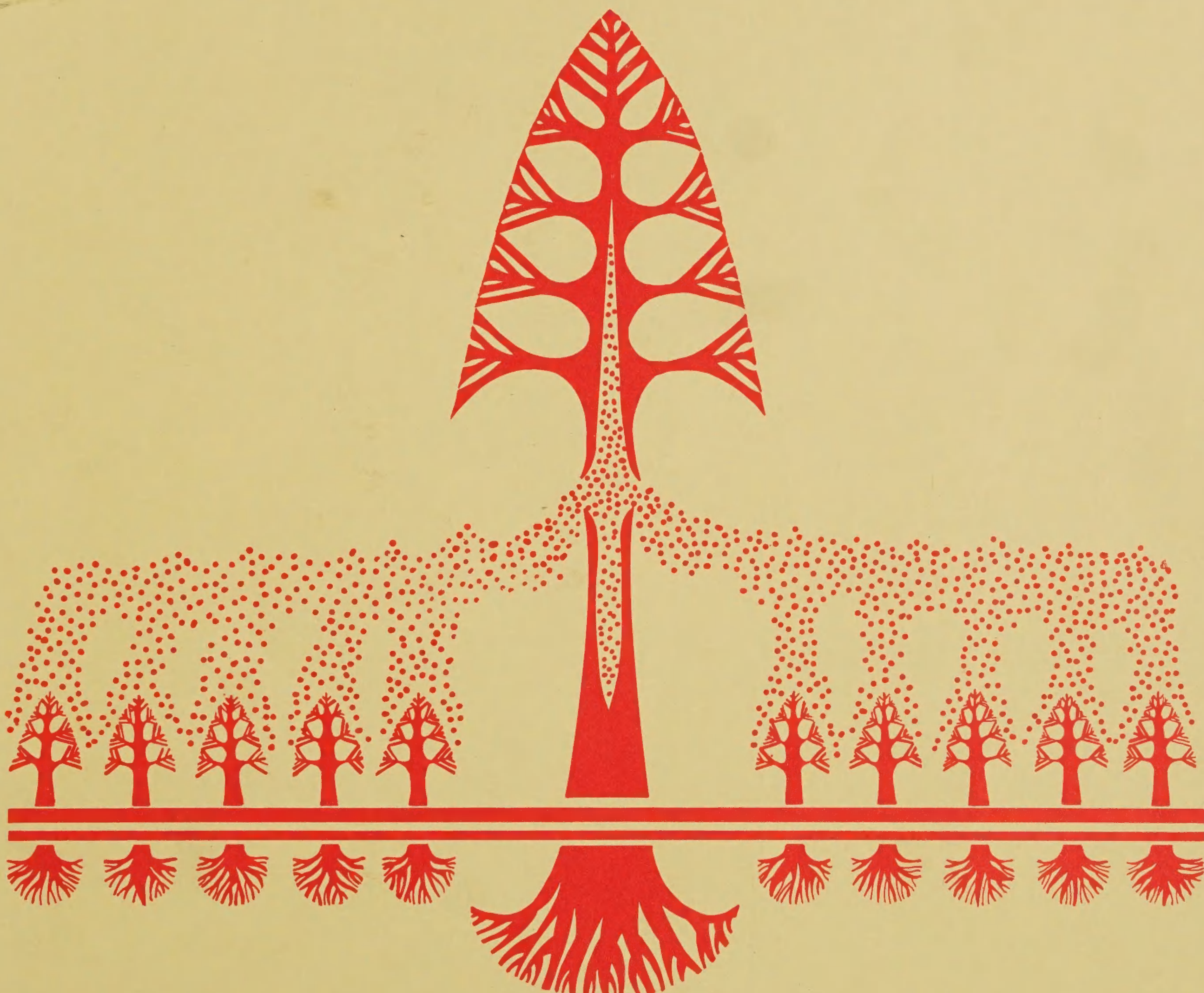
Indian Paint Fungus:

A Method For Recognizing And Reducing Hazard In Advanced Grand And White Fir Regeneration In Eastern Oregon And Washington



United States
Department of
Agriculture

Pacific Northwest Region
Forest Service

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A Method For Recognizing And Reducing Hazard In Advanced Grand And White Fir Regeneration In Eastern Oregon And Washington

By
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Preface

This guide presents a method for recognizing and reducing heartrot caused primarily by the Indian paint fungus. It has been prepared for foresters and others concerned with managing advanced white and grand fir regeneration in eastern Oregon and Washington.

The information presented in this guide was compiled from several sources and represents more than 20 years of research and observations by forest pathologists in the Pacific Northwest. Some of the information presented is based on research that is still in progress. This guide may be revised periodically as new information becomes available.

I. The Problem

White fir *(Abies concolor)* and grand fir *(A. grandis)* are closely related species that are major components of forest stands in southern Oregon and east of the Cascade Crest in Oregon and Washington. Many former ponderosa pine *(Pinus ponderosa)* stands gradually have changed to fire-intolerant white or grand fir as a result of an 85-year fire exclusion policy and past cutting practices of leaving true firs and harvesting the more valuable associated species. However, the rising value of forest products has brought increased emphasis on the need to intensively manage true fir forests. True firs are favored for intensive management in many areas because of their wide ecological amplitude, excellent growth potential, and ease of regeneration.

Losses due to heartrot in mature or overmature white and grand fir stands often are very severe. The Indian paint fungus *(Echinodontium tinctorium)* is responsible for nearly 80 percent of the decay in old-growth grand fir stands in the Blue Mountains of eastern Oregon and Washington (1, 3). A similar incidence of decay caused by *E. tinctorium* occurs in old-growth white fir in southern Oregon as well (2, 5).

In our survey of advanced white and grand fir regeneration in eastern Oregon and Washington, we found nearly 30 percent of the decay caused by the Indian paint fungus and the remainder by other fungi including *Pholiota limonella, Haematostereum sanguinolentum,* and *Hericium abietis.* Infections caused by *Fomes annosus, Armillaria mellea,* and *Phellinus weirii* are also common and often kill advanced regeneration before appreciable decay occurs (11).

Following partial cutting in East Side stands, many sites are still well stocked with advanced white or grand fir regeneration (Figure 1). By managing this advanced regeneration and thus avoiding extensive planting and site preparation costs, forest managers can realize a better return on their investment at harvest provided decay volumes are small. Also, it may take several planting attempts to reforest some sites – if they can be reforested at all – after removal of the overstory and advanced regeneration. Therefore, critical concerns of foresters desiring to manage white and grand fir regeneration

Figure 1. Following partial cutting in East Side stands, many sites are still well stocked with advanced white or grand fir regeneration.

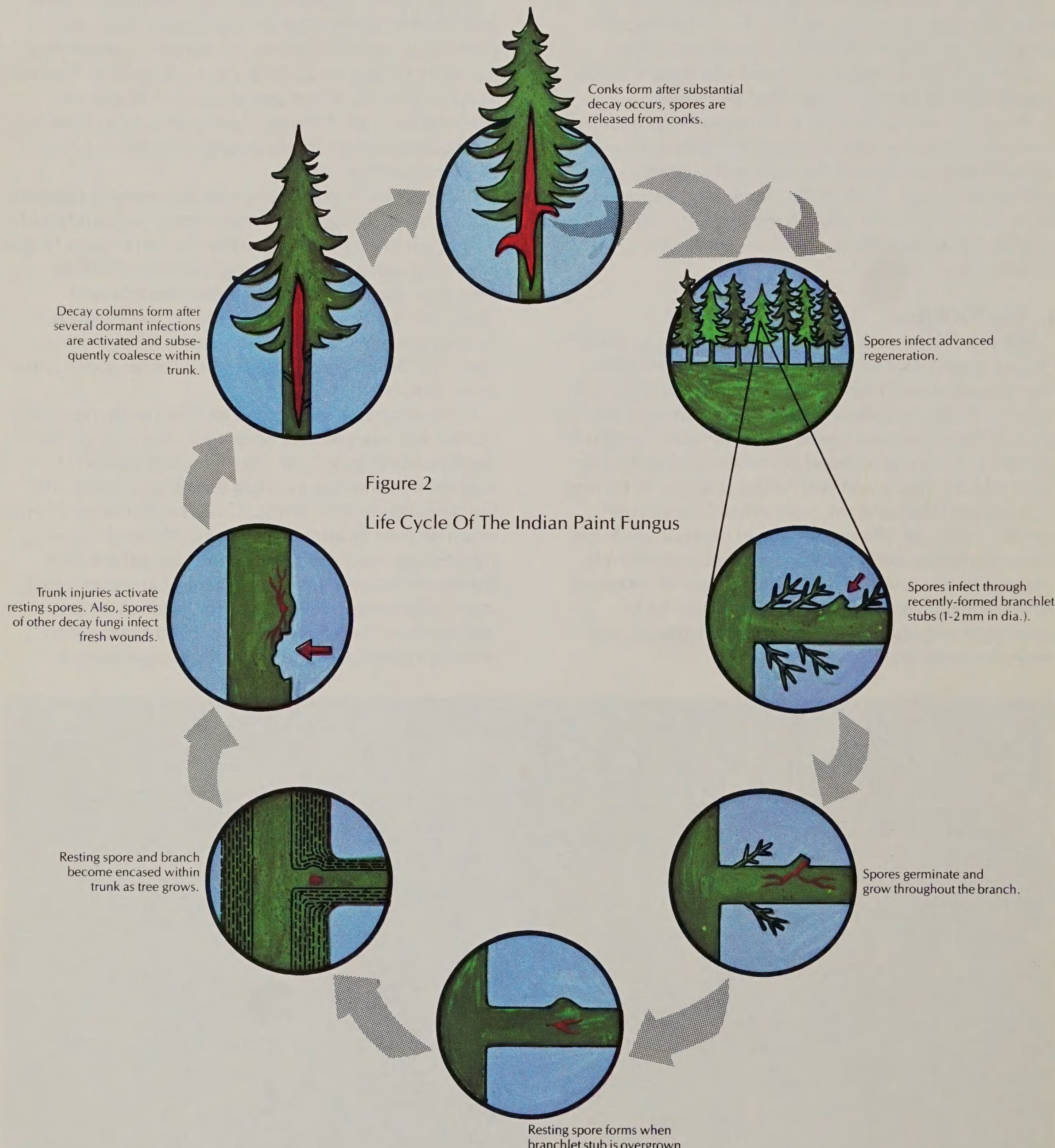


Figure 2

Life Cycle Of The Indian Paint Fungus

are the current levels of Indian paint fungus infection and decay and, perhaps more importantly, the expected amount of heartrot, especially at harvest age. This guide describes a nondestructive sampling method to aid in making management decisions concerning this heartrot.

II. Fungus Biology

A. Biology of the Indian paint fungus

The life cycle of the Indian paint fungus is illustrated in Figure 2. The most conspicuous sign of the Indian paint fungus is the sporophore or conk which is large and woody with a black, cracked upper surface; a gray, toothed lower surface; and a brick red interior (Figures 3 and 4). The red interior was used by Indians for paint, hence the common name.

Viable spores are produced by the conks throughout the year (9, 12). However, optimal conditions for sporulation and germination occur during the spring and fall when temperatures periodically fall below 40°F, and mean daily temperatures are between 40 and 65°F. High levels of humidity are not required for sporulation except at temperatures above 40°F.

Figure 4. Advanced decay caused by the Indian paint fungus is the culmination of prolonged fungus attack.

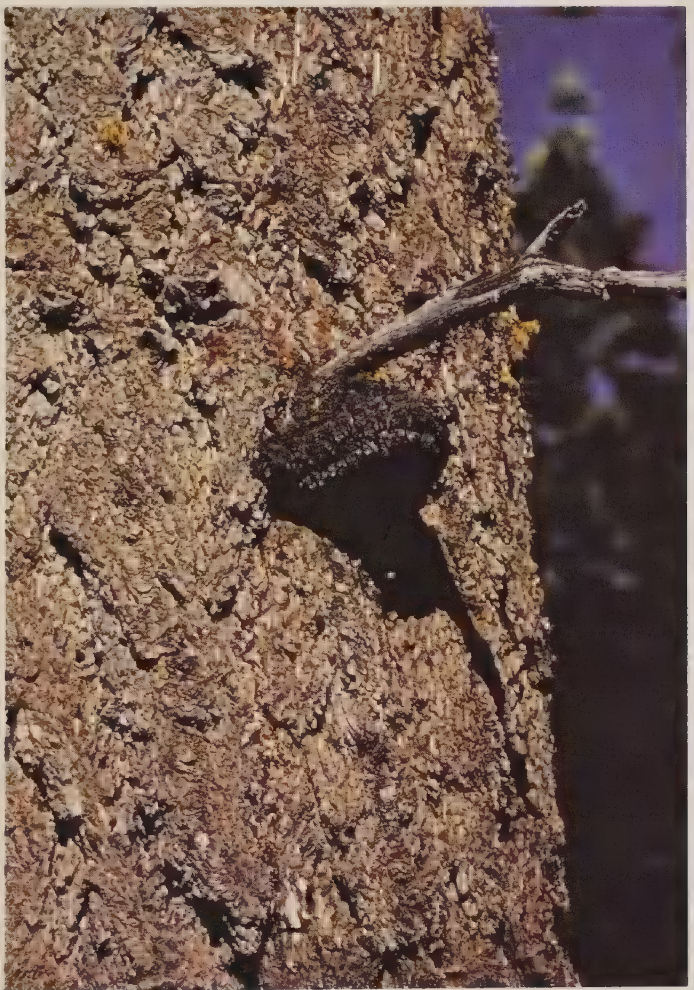


Figure 3. Typical conk of the Indian paint fungus often forms at old branch stubs.

Spores of the Indian paint fungus do not infect wounded tissues or old branch stubs as was once thought. Instead, spores infect small (less than 2 mm diameter) exposed branchlet stubs just before these stubs are overgrown (4, 6). A minimum of 40 years is necessary for the formation of branchlet stubs. These form when dead branchlets less than 2 mm in diameter break off at their base and expose presumably sterile wood to infection. Suppressed and slowly growing trees or branches heal these branchlet stubs very slowly, thus allowing more time for infection by Indian paint fungus spores. Also, suppressed branches have more shade-killed branchlets and thus produce more branchlet stubs or potential infection courts. Trees or branches that are growing vigorously heal branchlet stubs more rapidly.

After spores have germinated and mycelium develops within the branch, fungal growth continues until branchlet stubs are overgrown. Once branchlet stubs are overgrown, the fungus enters a dormant state in the form of a resting spore (chlamydospore) which can survive for 50 or more years without causing decay.

Dormant infections are activated immediately by mechanical injuries, frost cracks, or formation of large branch stubs that allow air to enter the trunk interior. Wounds must be within 1 foot of dormant infections. Even the smallest wounds, including attacks by fir engravers *(Scolytus ventralis),* can activate dormant infections. However, several factors (discussed on Page 4) determine the amount of subsequent decay. Also, the larger an injury, the more likely that one or more dormant infections will be activated and cause decay.

Although a single suppressed tree may have several infections, relatively few cause trunk decay because (1) infections need to be within the trunk (trunk-encased branches) or immediately adjacent to the trunk in branches, (2) most infections become dormant and are not activated because wounding is too far from infections, and (3) infections probably do not survive after branch death except in branches that have become encased within the trunk.

Reactivated infections first cause elongated areas that are stained light brown or yellow. At this incipient stage, the structural properties of the wood are not visibly altered. However, affected wood is unsuitable for many uses, even in the earliest stages of decay (12). Advanced decay, which appears yellow- to reddish-yellow and fibrous or stringy (Figure 4), is the culmination of prolonged fungus attack. Extensive heartrot columns may occur after several dormant infections become active, cause decay, and subsequently coalesce.

After extensive decay has formed, conks are produced, often at old branch stubs and occasionally at wounds where the fungus has a continuous pathway from the interior to the outside of the tree. Spores can be produced for several years after conks have formed. Also, spores may be produced for at least 10 years from conks on trees that have died or have been felled (12). Felled trees produce more conks than standing dead trees. Also, conk survival is poorer on trees bucked into logs than on felled but intact trees. The percentage of conks surviving on moderately- to heavily-shaded logs is twice that on lightly-shaded logs.

The Indian paint fungus can complete its life cycle in several coniferous species including white fir, grand fir, Pacific silver fir *(A. amabilis)*, noble fir *(A. procera)*, Shasta red fir *(A. magnifica)*, subalpine fir *(A. lasiocarpa)*, western hemlock *(Tsuga heterophylla)*, mountain hemlock *(T. mertensiana)*, and rarely in Douglas-fir *(Pseudotsuga menziesii)*, and Engelmann spruce *(Picea engelmannii)*. Damage is most severe in white and grand fir and, perhaps, mountain hemlock. In some areas, other species may be extensively infected, but decay volumes generally are less than in white or grand fir.

B. Biology of Other Decay Fungi

Other decay fungi besides Indian paint fungus, including *F. annosus, H. sanguinolentum, P. limonella,* and *H. abietis,* infect advanced white and grand fir regeneration by means of basidiospores released from conks or mushrooms. Spores infect fresh wounds and, in some cases, follow a succession of other microorganisms such as bacteria, yeasts, and nondecay fungi. More decay is associated with larger, older wounds in contact with the soil where moisture conditions are more favorable for decay development. Conks or mushrooms appear after advanced decay develops.

Fungi, such as *A. mellea* and *P. weirii,* that cause root rots and butt rots in white and grand fir, infect vegetatively by underground spread of mycelium across root contacts and grafts. Aerial infection by spores of these fungi is negligible, hence wounds are not necessary for infection. *F. annosus,* the second most common decay fungus in advanced grand and white fir regeneration, infects both vegetatively through root contacts and aerially by basidiospores through fresh wounds.

The condition known as wetwood is extremely common in white and grand fir (15) and resembles early stages of decay. Wetwood is a type of heartwood usually at the base of standing trees that has been infused internally with water. The exact cause of wetwood is uncertain, but has been attributed to several factors: microbial (bacteria), nonmicrobial (injury), and normal age-growth formation. Wetwood is not incipient decay and will not become advanced decay. In fact, wetwood actually may prevent advanced decay. Wetwood, however, can cause substantial economic loss when affected timber is converted into logs and products by causing shake, collapse, honeycomb, ring failure, warpage, and slower drying rates.

C. Generalizations Concerning Decay

The following generalizations apply to decay from all causes in advanced white and grand fir regeneration in eastern Oregon and Washington:

- Trees compartmentalize decay, that is, decay columns will not exceed the diameter of the tree when wounding occurred unless additional wounding takes place (14).
- Amount of decay in a stand increases from upper slope to lower slope (12); moisture conditions are more favorable for infection and decay at lower slopes, especially near watercourses.
- Amount of decay is greater on northerly versus southerly aspects; moisture conditions are more suitable for decay development on northerly aspects.
- Amount of decay increases with increasing number of Indian paint fungus infections; this fungus causes 80 percent of the decay in mature grand and white fir (1, 3).
- Amount of decay is greater where overstories are dominated by true firs or Douglas-fir rather than pines; true fir overstories have a higher likelihood of containing conks and mushrooms, hence more spores are present; also moisture conditions are more suitable for infection and decay under the denser true fir or Douglas-fir overstories than under the more open pine overstories.

• Amount of decay increases proportionally with stand age and diameter where diameter is directly proportional to age (3).

• Amount of decay increases proportionally with frequency of tree wounding in the stand (3, 7, 8, 9, 10); wounds both activate dormant Indian paint fungus infections and provide entry courts for other decay fungi.

• Amount of decay increases with wound size and age; also, basal wounds have more decay than upper stem wounds, age and size being constant (3, 14).

• Amount of decay is influenced by tree genetics; some trees within a species are more resistant to decay than others, all other factors being equal.

• Decay may be caused by a single species of decay fungi, but infections by two or more species are common (3).

• Amount of decay (butt rot) is influenced by the distribution and species of root pathogens on the site (11).

III. Hazard Rating Method

A. Infection and Decay Equations

Two equations were developed to estimate the percentage of infection (by Indian paint fungus) and heartrot (by all decay fungi) in advanced white and grand fir regeneration in eastern Oregon and Washington. The first equation estimates the percentage of potential crop trees with both dormant and active trunk infections of the Indian paint fungus (ET%):

$$LOG_N(ET\%) = 1.1832\ (OVER) - 0.0632\ (LCR) + 6.3909$$

where OVER = Primary overstory species (0 = pine, 1 = fir)

LCR = Mean crop tree live crown ratio (percent)

LOG_N = Natural logarithm ($R^2 = 0.42$, SE = 0.98)

The second equation estimates the percentage of crop tree volume (ft.^{3}) with both incipient and advanced decay caused by all decay fungi including *F. annosus, P. limonella, H. abietis,* and *H. sanquinolentum* as well as *E. tinctorium,* the primary cause of decay.

$$LOG_N(DEC\ VOL\%) = 1.8219\ LOG_N(AGE) + 0.8386\ LOG_N(WND\%) - 0.4151\ (ASP) - 10.4222$$

where AGE = Mean crop tree total age

WND% = Percentage of crop trees with one or more wounds or conks

ASP = Stand aspect (0 = N, NW, NE, W; 1 = S, SE, SW, E)

LOG_N = Natural logarithm ($R^2 = 0.70$, SE = 0.79)

Both equations can be programmed on handheld calculators (ET and FIROT programs, Appendix).

B. Stand Sampling Procedures

Depending on stand shape, follow one or more parallel transects through the stand and select one potential crop tree (based on height, form, live crown ratio, and wounding) nearest a sample point located every two or three chains along the transect. The idea is to systematically obtain at least 20 sample trees per stand. If previous stand exam data are available, these may be used, but additional information may need to be collected. Large stands varying widely in aspect or wounding frequency should be stratified into homogeneous units and each unit sampled separately.

C. Stand and Tree Characteristics Measured

a. ***Primary Overstory Species (OVER)***—Determine if the overstory is (or was) dominated by pine (ponderosa, lodgepole/*P. contorta,* white/*P. monticola,* sugar/*P. lambertiana*) or fir (true fir, hemlock, or Douglas-fir). If 60 percent or more of the volume or the basal area is pine, enter "0". If more than 40 percent is fir, enter "1". If the overstory is no longer present, (1) examine stumps to determine overstory species, or (2) use plant community classifications to determine overstory species. Code as fir for true fir, hemlock, or mixed conifer types. Code as pine for lodgepole or ponderosa dominated forest types.

b. ***Aspect (ASP)***—Record the aspect of the stand. Enter "O" for northerly aspects (N, NW, NE, or W) or "1" for southerly aspects (S, SE, SW, E).

c. ***Percentage of Crop Trees Wounded or With Conks (% WND)***—Record if the crop tree has one or more wounds ($\geq$ 1 in.^{2}) or trunk conks (any species). Include top breaks, dead tops, frost cracks, fire scars, and wounds on major exposed roots. Sum the number of trees with one or more wounds or conks and divide by the number of sample trees in the stand to obtain the percentage of trees with wounds or conks. The method was designed for stands with more than 15 percent but less than 90 percent of the trees wounded or with conks. Also, if most wounds are recent (less than 10 years old), actual current decay volumes may be less than estimated. If average size of wounds for the stand exceeds 2 ft.^{2}, actual current decay volumes may be higher than estimated.

d. ***Mean Crop Tree Live Crown Ratio (LCR)***—Obtain live crown ratio (nearest 5 percent) for each crop tree. Divide the length of live crown (as measured from the top of the tree to the last major live branch where it joins the stem) by total tree height. Sum the individual crown ratios and divide by the number of samples to obtain mean crop tree live crown ratio. The method is limited to stands with mean LCR's greater than 60 percent but less than 85 percent.

e. ***Mean Crop Tree Age (AGE)***—Obtain the total age for each crop tree by increment boring at breast height and adding the appropriate number of years to give total age. Sum the individual ages and divide by the number of samples to obtain mean crop tree age. Stands less than 40 years old will have no Indian paint fungus infections and little or no decay.

f. ***Optional—Mean Crop Tree DBH and Mean Current Radial Increment***—Measure the DBH and the last 10-year radial growth for each crop tree and average for the stand. Although DBH and current increment are not needed to estimate percentage of infection or decay, they may be useful when determining years for additional diameter growth to reach merchantability.

D. Limitations on Use

Besides the limitations already expressed for each variable, other restrictions on the use of the sampling method should be mentioned. The method was developed for advanced regeneration stands east of the Cascade Mountains in Oregon and Washington, especially in the Blue Mountains. If the method is used in white or grand fir stands west of the Cascade Mountains, in California white fir stands, or in grand fir stands in British Columbia or Idaho, values obtained may not be valid since the method was not developed in these areas. Likewise, the method was not tested for other conifers that serve as hosts for the Indian paint fungus such as noble fir, Pacific silver fir, subalpine fir, Shasta red fir, western hemlock, and mountain hemlock. By using the procedures outlined in this guide (Appendix), it may be possible to test existing equations or develop new equations for other species and areas.

E. Estimating Future Decay

Not only can the two equations be used to estimate the current incidence of infection and decay, the equation for estimating decay can be used to predict percentage of decay (both cubic and board-foot) at any point in the future since *mean crop tree total age* is a variable in the equation. Also, the variable *percentage of crop trees with wounds or conks* can be increased, especially if future stand entries will be made.

Wounding of residual trees during commercial thinning operations has been shown to vary from 5 to 14 percent when methods designed to reduce damage are used and 22 to 50 percent when conventional logging techniques are used (7, 8). An increase in *percentage of crop trees with wounds or conks* by adding 25 percent for commercial thinning, could be used in making decay projections, but local knowledge of wound incidence following typical entries would yield more accurate estimates. Wounds made within 10 years of stand harvest can be ignored because decay would not have sufficient time to develop. Wounding incidence would probably be less during precommercial thinning, but more for overstory removals depending on the volume removed. In making decay projections, it should be assumed wounding would increase 1 percent every decade because of naturally-caused wounds.

Board-foot (Scribner) defect percentages can be calculated for stands $\geq$11 inches DBH by multiplying cubic foot decay percentages by 2.7 (3). Board-foot defect percentages are always higher than cubic foot decay percentages because of scaling differences between cubic and board-foot measures. Also, board-foot defect percentages include deductions for shake, frost cracks, and sound volume lost in cull logs, as well as decay.

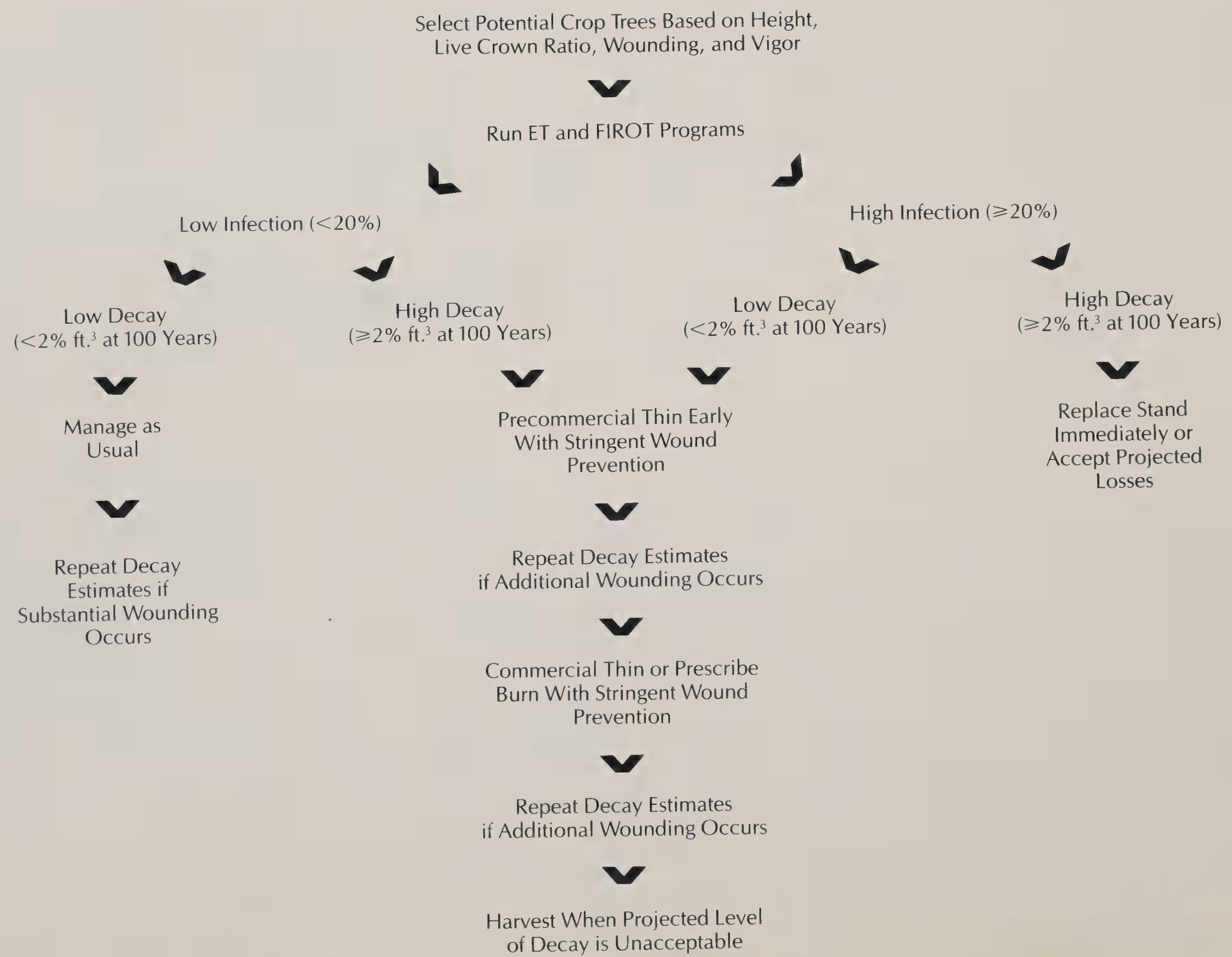
F. Interpreting the Results

The decision to retain or destroy stands of advanced white or grand fir regeneration and the management of stands to be retained should be influenced by infection and decay estimates. A decision key is provided (Figure 5) concerning these estimates and is explained as follows:

Potential crop trees with low infection levels (<20%) *and* low decay percentages (<2% $ft.^3$ at 100 years) generally have a relatively low incidence (<25%) of wounding and good live crown ratios ($\geq$50% under pine overstories or $\geq$75% under fir overstories). Provided that root disease centers are not present, such stands can be managed for extended rotations (150 to 200 years) with no special precautions provided that substantial injury does not occur and reasonable increment is maintained. Decay estimates should be recalculated if substantial amounts of wounding occur either naturally or following stand entries.

Potential crop trees with low infection levels (<20%) *but* high decay percentages ($\geq$2% $ft.^3$ at 100 years) have a high incidence of wounding (($\geq$25%) and good live crown ratios ($\geq$50% under pine overstories or $\geq$75% under fir overstories). Such stands should not be managed for extended rotations but can be managed on rotations less than 150 years provided that special precautions are taken. Stands should be precommercially thinned early with stringent restrictions against crop tree wounding. Most decay columns that may result from thinning wounds on small trees will be relatively small—no larger than the diameter of the tree at the time of wounding. Wounding resulting from stand entries should be prevented unless stands will be harvested within 10 years. Wounds created within 10 years will not have sufficient time to develop decay. Decay estimates should be made after each entry

Figure 5 **Decision Key That Incorporates Infection And Decay Estimates Into True Fir Management**



if additional wounding occurs. Stands should be harvested when projected decay levels become unacceptable.

Potential crop trees with high infection levels (≥20%) *and* low decay percentages (<2% ft.^{3} at 100 years) generally have a low incidence (<25%) of wounding but poor live crown ratios (<50% under pine overstories or <75% under fir overstories). Such stands should be managed similarly to stands with low infection but high decay percentages provided that crop tree live crown ratio ≥50 percent and leader growth is good (8 in./year) to insure release.

Potential crop trees with high infection levels (≥20%) *and* high decay percentages (≥2% ft.^{3} at 100 years) have a high incidence (≥25%) of wounding and poor live crown ratios (<50% under pine overstories or <75% under fir overstories). Such stands should be replaced immediately or the fir component destroyed unless projected percentages of decay are acceptable.

Examples of how white or grand fir stands should be rated and managed based on estimates of infection and decay are presented for 23 stands sampled in eastern Oregon and Washington (Table 1). Each stand was assigned a hazard code of 1, 2, 3, or 4 as follows: 1 = low infection (<20%) and low decay (<2% ft.^{3} at 100 years); 2 = low infection, high decay; 3 = high infection, low decay; and 4 = high infection, high decay. Hazard codes correspond to management guidelines in Figure 5.

Thirteen percent of the 23 stands can be managed to extended rotations (150 to 200 years). Nearly two-thirds (61%) of the stands should be managed on rotations less than 150 years with special precautions. Over one-quarter (26%) of the stands should be replaced now or should have been replaced in the past.

IV. Stand Management

The following management recommendations are suggested for minimizing heartrot in grand and white fir in eastern Oregon and Washington where timber production is to be optimized:

1. ***Manage on Short Rotations*** – Keep rotations less than 150 years unless estimated amount of Indian paint fungus infection is <20% and decay <2% ft.^{3} at 100 years.

2. ***Do Not Avoid or Delay Early Thinning Because of Perceived Potential Decay Losses*** – Growth increases due to thinning in most cases will outweigh decay losses. Increased vigor due to thinning will prevent Indian paint fungus infection. Thin early so that potential decay columns, should they develop as a result of wounding, will be relatively small due to compartmentalization.

3. ***Select Crop Trees Based on the Following Characteristics*** – Trees should have:
   a. at least 50 percent live crown ratio
   b. at least 8 inches of current leader growth (to insure release)
   c. no wounds or top damage
   d. the best form and height.

4. ***Minimize Wounding*** – Wounds can and should be prevented when thinning, prescribed burning, disposing slash, or removing the overstory because of the potential losses due to decay and other defects associated with injuries. Actions can be taken – both in the planning process and during the actual operation – to prevent much of this damage.

   a. ***Restrict the Operating Season*** – Refrain from stand operations during the spring and early summer when the sap is flowing and bark is not tight. Injuries occurring during this time often result in damage to residual trees that would never occur later in the year.

   b. ***Restrict Size and Type of Operating Equipment*** — Attempt to match the size and type of operating equipment with topography, tree size, and soil type and condition.

   c. ***Mark "Leave" Trees Rather Than "Cut" Trees*** – This will significantly decrease damage to residual trees.

   d. ***Plan Skid Trails Before Logging*** – Straight-line skid trails should be used whenever possible, but at all times, avoid sharp turns. Straight-line patterns not only decrease skidding distances, but they also eliminate the excessive damage that occurs at turns. Clear skid trails only slightly wider than the skidding vehicle, preferably not wider than about 8 feet. Leave "bump" trees or cull logs along the edges of skid trails.

   e. ***Match Log Length With Final Spacing*** – A close final spacing calls for skidding relatively short logs while wider spacing allows longer logs to be skidded with minimal damage to residuals. Tree length skidding increases damage to residual trees.

   f. ***Log Skid Trails First*** – Trees located on skid trails should be felled and skidded prior to harvesting other timber. If trees in skid trails are felled in conjunction with other trees in the stand, it becomes difficult for fallers to locate the skid trails and to fall the timber to lead.

   g. ***Cut Low Stumps in Skid Trails*** – Stumps within skid trails should be cut as low as possible (preferably 3 or 4 inches high) to prevent the skidder from being shunted sideways into residual trees.

   h. ***Use Directional Falling*** – Trees should be felled 45° either directly toward or directly away from skid trails. This will reduce skidder maneuvering and load pivoting and thus damage to residual trees.

i. ***Limb and Top Trees Prior to Skidding***—Limbs should be cut flush to the bole; stubs should not be left that can easily redirect a skidded tree into crop trees.

j. ***Remove Slash from Around Crop Trees if Stands are to be Underburned***—Excessive temperatures at the base of trees often cause wounds that lead to butt rot. Removal of woody material from the base of residual trees will reduce basal wounds caused by fire. Good fire management is good decay management.

k. ***Gain the Cooperation of the Operator***—Operators must be convinced that most damage to residual trees is unnecessary and will not be tolerated. Both training and supervision are often needed to insure the desired results.

5. ***Wound Dressings are Unnecessary***—Unfortunately, there are no chemical or biological methods for protecting trees from infection once they are injured. After the decay process begins in a tree, there is no economical way to stop it.

6. ***Stump Treatments are Usually Unnecessary***—Following thinnings or harvesting, treating stump surfaces with chemicals, usually sodium borate, is unnecessary unless severe mortality caused by *Fomes annosus* has been observed in adjacent stands and stumps are free from decay. Stump excavation or treatment with volatile fumigants is usually unnecessary unless stands have severe mortality caused by root diseases, and conversion to more resistant species is neither desirable nor possible.

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Figure 6

Map Showing Locations Of The 23 Original And 22 Additional Stands Sampled For Indian Paint Fungus

1. Sullivan Lk.
2. Newport
3. Entiat
4. Lk. Wenatchee
5. Cle Elum
6. Naches
7. Naches
8. Pomeroy
9. Walla Walla
10. Walla Walla
11. Eagle Cap
12. Wallowa Vy.
13. LaGrande
14. LaGrande
15. Ukiah
16. Baker
17. Baker
18. Baker
19. Long Creek
20. Prairie City
21. Prairie City
22. Prairie City
23. Bear Valley
24. Big Summit
25. Sisters
26. Bend
27. Silver Lake
28. Chiloquin
29. Klamath
30. Lakeview

Acknowledgements

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Appendix

Method Development

Twenty-three stands on eight National Forests east of the Cascade Mountains of Oregon and Washington (Figure 6, Table 2) were examined to develop a non-destructive sampling method for estimating infection and decay levels in advanced white and grand fir regeneration. Sampled stands had been entered several times in the past to remove the more valuable species (Douglas-fir, ponderosa pine, western larch *(Larix occidentalis)* resulting in residual tree wounding of highly variable ages. Only stands with advanced regeneration dominated by white or grand fir were sampled. Other advanced regeneration species occasionally present but not sampled included ponderosa pine, lodgepole pine, and Douglas-fir. Advanced regeneration ranged in age from 43 to 115 years and in DBH from 3.6 to 7.8 inches.

Three or four parallel transects three to five chains apart were used to sample each stand. One potential crop tree distinguished by height and form was selected nearest a sample point located every five chains along transects. Only potential crop trees were sampled since it was assumed that noncrop trees would be destroyed during stand improvement. Twenty trees were sampled in each stand (460 trees total).

Stand information collected included:

- Primary Overstory Species (by vol. or basal area)
- Crop Species (white or grand fir dominating)
- Topographical Position (upper, mid, or lower slope)
- Percent Slope (nearest 5 percent)
- Aspect (N, NE, E, SE, S, SW, W, or NW)
- Elevation
- Years Since Last Entry

Information collected from each tree before felling included:

- Tree Species (white or grand fir)
- DBH (nearest 0.1 inch)
- Epicormic Branch Height (nearest foot)
- Wound Type (root, basal, below BH, above BH, frost crack)

And after felling:

- Total Height (nearest 0.1 foot)
- Length of Live Crown (nearest 0.1 foot)
- Total Age
- Wound Age
- Wound Size (length X width, nearest 0.1 foot)
- First 50-Year Radial Growth (on three random radii at stump, nearest 0.01 in.)
- Last 10-Year Radial Growth (on three random radii at stump, nearest 0.01 in.)
- Last 10-Year Leader Growth (nearest 0.1 foot)

All sample trees were returned to the laboratory to determine presence and identity of decay fungi and amount of decay. Each tree was dissected at the ground line and at ½ to 1-foot intervals to just above the lowest whorl of live branches.

Each section was split aseptically to expose stem and twig piths, wetwood, stain, and decay. Wood chips were removed aseptically from freshly exposed sections and placed in culture tubes containing 2 percent malt agar. Isolations were attempted from healthy-appearing stem and twig piths, wetwood, and stained or decayed wood. Cultures were incubated for 6 weeks at room temperatures in the dark after which all decay fungi were recorded and identified to genus and, if possible, species.

The cubic foot volume of each tree and of incipient and advanced decay (wetwood was not measured) was determined using Smalian's formula. Board-foot volumes of logs (in trees 11 inches DBH and greater) were computed by the Scribner log rule, and board-foot deductions for decay, shake, and frost cracks were made by the squared defect method. Logs were considered cull if less than one-third sound. Cubic volumes were not calculated for trees less than 4.0 inches DBH. Volumes for stands with a mean DBH less than 4.0 inches were estimated from volume tables. Cubic foot measurements were calculated to a 4-inch top and board-foot measurements to an 8-inch top.

To develop an equation to estimate future incidence of decay, it was necessary to use data from an older age class of trees. Data from 22 stands on three National Forests in the Blue Mountains of Oregon and Washington (Figure 6, Table 3) were combined with data from the original 23 stands. Blue Mountain stands ranged in age from 77 to 259 years and in DBH from 7 to 24 inches (3).

Data from both sets of stands were collected similarly except that the following characteristics were not measured in Blue Mountain stands: topographical position, years since last thinning, live crown length, wound age, size and type, epicormic branch height, and last 10-year radial and leader growth. Also, trees in Blue Mountain stands were selected from within fixed-area plots along parallel transects, and 12 to 124 trees were selected from each stand (1,090 trees total).

The following stand characteristics were subjected to multiple regression analysis to determine significance and develop predictive equations:

Dependent Variables:

1. Percentage of True Fir Crop Trees with Indian Paint Fungus Infections
2. Percentage of True Fir Crop Tree Volume ($ft.^3$) with Decay

Independent Variables:

*Significant (P = 0.01)

	Dept. Var. #1	Dept. Var. #2
1. Primary Overstory Species	*	
2. Mean Crop Tree Live Crown Ratio	*	
3. Percentage of Crop Trees with One or More Wounds or Conks		*
4. Mean Crop Tree Total Age		*
5. Stand Aspect		*
6. Stand Topographical Position		1/
7. Percent Slope		
8. Mean Stand Elevation		
9. Years Since Last Thinning		1/
10. Mean Crop Tree DBH (Arithmetic)		
11. First 50-Year Radial Growth		
12. Last 10-Year Radial Growth		1/
13. Last 10-Year Leader Growth		1/
14. Wound Type, Age, and Size		1/
15. Epicormic Branch Height		1/

1/ Variable not used because of missing data from Blue Mountain stands.

Variables needed to be significant at F = 2.0 or greater to enter equations. Only data from the original 23 stands were used to develop equations to estimate percentage of crop trees with Indian paint fungus infection.

Only the current percentage of trees with trunk infections was estimated since most branch infections that do not become encased in the trunk will not cause heartrot. Future trunk infection percentages probably will increase as branch infections become encased within expanding trunks. The infection equation explains less than half of the variation in *E. tinctorium* infection ($R^2 = 0.42$). This is probably due to the extreme difficulty in determining which trees were infected with Indian paint fungus, especially dormant infections. Some delays in sample processing and the difficult culturing of *E. tinctorium* may have contributed to estimates lower than actual infection. Because of the low coefficient of determination (R^2) estimates of the percentage of trees with *E. tinctorium* infection should be viewed as approximations categorized as either high (≥20%) or low (<20%) infection levels; 20 percent being the Regionwide sample mean.

The significant variables in the infection equation, primary overstory species and live crown ratio, are supported by empirical data concerning Indian paint fungus infection. Stands with primarily fir overstories have more conks and thus more inoculum than stands with pine overstories. Also, stands with fir overstories are generally more dense and shaded, thus providing more favorable conditions for infection than stands with pine overstories.

Live crown ratio has been shown to be one of the best variables explaining growth rate in advanced grand and white fir regeneration (12). Trees with lower live crown ratios are more suppressed and, therefore, are more likely to become infected with the Indian paint fungus through recently formed branchlet stubs. Branchlet stubs are more abundant and slower healing on suppressed trees.

The significant variables in the decay equation are supported by empirical data concerning decay in living trees. As tree age increases, so does the amount of decay (3, 12). This may be related to the accumulation of wounds with time and the increased time for decay development. Presence of wounds or conks has always been a reliable indicator of heartrot in true firs (1, 2, 3, 5). Size, age, and type of wounds influence the amount of decay. There was not enough variation, however, in our samples to detect these effects. Consequently, wound size, age, and type are not significant variables in the equation, and from an operational standpoint in the forest, this is advantageous. Any species of conk on the tree is a reliable decay indicator.

Table 1. **Projected Decay Percentages For White And Grand Fir Stands Sampled In Eastern Oregon And Washington**

Stand Location (Ranger Dist.)	CURRENT AGE					AGE 100		AGE 200			AGE 200 THINNED			
	AGE	WND % [1]	DEC. VOL. % CF	ET (%) [2]	ASPECT [3]	WND % [4]	DEC. VOL. % CF	WND % [4]	DEC. VOL. % CF	DEC. VOL. % BF	WND % [5]	DEC. VOL. % CF	DEC. VOL. % BF	Hazard Code [6]
LaGrande	109	40	3.4	36.8	0	39	2.8	49	12.1	32.7	74	17.1	46.2	4
La Grande	61	50	1.4	10.0	0	54	3.7	64	15.2	40.9	99	21.9	59.0	2
Baker	72	45	1.8	15.9	0	48	3.4	58	14.0	37.7	83	18.8	50.9	2
Baker	68	15	0.6	2.7	0	18	1.5	28	7.6	20.5	53	12.9	34.9	1
Long Ck.	73	45	1.8	4.4	0	48	3.4	58	14.0	37.7	83	18.8	50.9	2
Bear Vy.	67	70	2.2	3.0	0	73	4.8	83	18.8	50.9	100	22.0	59.5	2
Prairie City	76	40	1.2	22.8	1	42	2.0	52	8.4	22.7	77	11.7	31.6	4
Prairie City	64	50	1.0	9.8	1	54	2.5	64	10.0	27.0	89	13.2	35.6	2
Lk. Wenatchee	90	55	2.1	28.4	1	56	2.5	66	10.3	27.7	91	13.4	36.3	4
Entiat	74	35	1.0	23.6	1	38	1.8	48	7.9	21.2	73	11.2	30.2	3
Naches	81	70	3.1	22.5	0	72	4.7	82	18.7	50.4	100	22.0	59.5	4
Naches	115	90	7.4	31.4	0	89	5.7	99	21.9	59.0	100	22.0	59.5	4
Cle Elum	84	80	3.8	18.2	0	82	5.3	92	20.5	55.5	100	22.0	59.5	2
Lakeview	68	60	1.3	3.3	1	63	2.8	73	11.2	30.2	98	14.3	38.6	2
Sullivan Lk.	64	65	1.3	23.9	1	69	3.0	79	11.9	32.2	100	14.6	37.3	4
Newport	43	30	0.3	16.3	1	36	1.7	46	7.6	20.5	71	10.9	29.5	1
Silver Lk.	71	40	1.5	3.7	0	43	3.1	53	12.9	34.9	78	17.9	48.3	2
Bend	104	80	3.7	12.3	1	80	3.4	90	13.3	36.0	100	14.6	39.3	2
Sisters	76	30	0.9	18.6	1	32	1.6	42	7.0	19.0	67	10.4	28.1	1
Big Summit	82	45	2.2	17.2	0	47	3.3	57	13.8	37.1	82	18.7	50.4	2
Wallowa Vy.	81	60	2.8	7.0	0	62	4.2	72	16.7	45.2	97	21.5	58.0	2
Chiloquin	69	40	1.5	13.4	0	43	3.1	53	12.9	34.9	88	19.8	53.5	2
Klamath	74	55	1.4	15.1	1	58	2.6	68	10.5	28.4	93	13.7	37.0	2

[1] Percentage of crop trees with one or more wounds or conks
[2] ET% estimated from equation
[3] Aspect: 0 = N, NE, NW, W; 1 = S, SW, SE, E
[4] 1% increase per decade
[5] 1% increase per decade + 25% increase for commercial thin at age 150
[6] 1 = low infection (<20%)/low decay (<2% $ft.^3$ at 100 years); 2 = low inf./high decay; 3 = high inf./low decay; 4 = high inf./high decay

Table 2. **Characteristics Of The Original 23 White And Grand Fir Stands Sampled In Eastern Oregon And Washington**

Stand Location (Ranger Dist.)	Mean Age (Yr.)	Mean DBH (In.)	Mean LCR (%)	Trees With Wounds or Conks (%)	Mean Last 10-Yr. Radial Growth (In.)	Overstory Species [1]	Aspect [2]	Trees With ET (%)[3]	Cubic Foot Vol. Decay (%)[4]
LaGrande	109	6.6	62.8	40	0.93	1	0	60	3.1
LaGrande	61	5.4	83.4	50	1.44	1	0	0	4.0
Baker	72	7.4	76.1	45	1.47	1	0	25	2.5
Baker	68	6.6	85.2	15	1.11	0	0	0	0.1
Long Creek	73	6.1	77.8	45	1.34	0	0	5	4.8
Bear Valley	67	4.1	83.7	70	0.97	0	0	10	6.0
Prairie City	76	3.6	70.4	40	0.47	1	1	5	1.3
Prairie City	64	7.7	83.8	50	1.33	1	1	20	1.4
Lk. Wenatchee	90	4.8	66.9	55	0.56	1	1	30	3.8
Entiat	74	3.8	69.8	35	0.52	1	1	28	0.9
Naches	81	7.8	70.6	70	0.86	1	0	10	3.0
Naches	115	6.9	65.3	90	0.95	1	0	20	3.0
Cle Elum	84	7.5	73.9	80	1.43	1	0	25	1.2
Lakeview	68	3.9	82.1	60	0.63	0	1	5	2.7
Sullivan Lk.	64	4.5	69.6	65	0.46	1	1	20	2.3
Newport	43	3.9	75.7	30	0.76	1	1	30	0.1
Silver Lk.	71	5.6	80.5	40	1.18	0	0	0	0.6
Bend	104	6.0	61.4	80	0.62	0	1	5	3.6
Sisters	76	7.5	73.9	30	1.11	1	1	25	0.4
Big Summit	82	6.8	74.8	45	1.25	1	0	25	2.1
Wallowa Vy.	81	6.9	70.3	60	1.34	0	0	20	0.3
Chiloquin	69	5.3	78.8	40	0.95	1	0	60	2.6
Klamath	74	6.5	76.9	55	1.04	1	1	5	1.7
Average	77	5.9	74.5	52	0.99	—	—	19	2.2

[1] Overstory species: 0 = Pine (≥60% Vol. or BA), 1 = Fir (>40% Vol. or BA)
[2] Aspect: 0 = N, NE, NW, W; 1 = S, SW, SE, E
[3] Actual values; includes only trunk infections (dormant and active)
[4] Actual values; deductions for decay (incipient and advanced) only

Table 3. **Characteristics Of The Additional 22 White And Grand Fir Stands Sampled In The Blue Mountains Of Oregon And Washington**

Stand Location (Ranger Dist.)	Mean Age (Yr.)	Mean DBH (In.)	Mean LCR (%)[1]	Trees With Wounds or Conks (%)	Mean Last 10-Yr. Radial Growth (In.)[1]	Overstory Species[2]	Aspect[3]	Trees With ET (%)[4]	Cubic Foot Vol. Decay (%)[5]	Board Foot Vol. Defect (%)[6]
Walla Walla	102	10.0	—	75	—	1	0	8	8.9	—
Wallowa Vy.	130	7.3	—	38	—	1	0	6	12.5	—
Pomeroy	124	8.2	—	27	—	1	0	6	4.2	—
Walla Walla	173	8.0	—	43	—	1	1	14	4.3	—
Ukiah	159	7.9	—	49	—	1	0	36	13.8	—
Eagle Cap	120	7.9	—	31	—	1	0	19	8.5	—
Baker	162	7.6	—	44	—	1	0	9	4.0	—
Prairie City	206	8.0	—	55	—	1	0	25	12.1	—
Prairie City	77	7.7	—	8	—	1	1	3	0.2	—
Long Creek	131	6.8	—	6	—	1	0	9	3.4	—
Prairie City	179	7.6	—	20	—	1	0	0	2.4	—
Walla Walla	157	23.3	—	52	—	1	0	19	9.0	27.5
Wallowa Vy.	219	19.9	—	77	—	1	0	49	32.0	61.4
Pomeroy	194	21.0	—	68	—	1	0	27	15.8	43.4
Walla Walla	178	22.5	—	65	—	1	1	24	7.5	21.7
Ukiah	211	20.4	—	77	—	1	0	57	18.0	61.3
Eagle Cap	153	18.1	—	62	—	1	0	44	23.0	62.2
Baker	209	18.8	—	82	—	1	0	24	8.2	23.6
Prairie City	259	19.9	—	82	—	1	0	49	22.1	59.2
Prairie City	103	18.9	—	26	—	1	1	0	0.8	3.7
Long Creek	200	18.0	—	62	—	1	0	55	22.4	63.7
Prairie City	255	20.2	—	79	—	1	0	15	16.5	42.9
Average	168	14.0	—	51	—	—	—	23	14.1	38.3

1 Data not included
2 Overstory species: 0 = Pine (≥60% Vol. or BA), 1 = Fir (>40% Vol. or BA)
3 Aspect: 0 = N, NE, NW, W; 1 = S, SW, SE, E
4 Actual values; includes only trunk infections (dormant and active)
5 Actual values; deductions for decay (incipient and advanced) only
6 Computed on stands ≥11.0 inches DBH; includes deductions for decay, shake, frost cracks, and sound volume lost in cull logs

Appendix

Equation One – Dependent Variable = $LOG_N(ET\%)$

Analysis of Variance

	DF	Sum of Squares	Mean Square	F
Regression	2	13.89923	6.94961	7.25269
Residual	20	19.16424	0.95821	

Variables in the Equation

Variable	B	BETA	STD ERROR B	F
OVER	1.183214	0.45408	0.46104	6.586
LCR	−0.063199	−3.5533	0.03147	4.033
(CONSTANT)	6.390908			

$R^2 = 0.42$ $SE = 0.98$

Equation Two – Dependent Variable = $LOG_N(DEC\ VOL\%)$

Analysis of Variance

	DF	Sum of Squares	Mean Square	F
Regression	3	58.81052	19.60351	31.23256
Residual	41	25.73416	0.62766	

Variables in the Equation

Variable	B	BETA	STD ERROR B	F
$LOG_N(AGE)$	1.821885	0.61055	0.28485	40.909
$LOG_N(WND\ \%)$	0.838626	0.34710	0.21495	15.222
ASPECT	−0.415086	−0.14020	0.27654	2.253
(CONSTANT)	−10.42219			

$R^2 = 0.70$ $SE = 0.79$

Programs for hand-held calculator (Hewlett-Packard 41 C/CV)[1] for ET and FIROT programs

ET Program

```
01 ◆ LBL "ET"
02   CLRG
03   CLA
04   "OVERSTORY?"
05   PROMPT
06   1.183214
07   *
08   "LCR?"
09   PROMPT
10   .063198
11   *
12   —
13   6.390908
14   +
15   E↑X
16   CLA
17   "ET%="
18   ARCL X
19   AVIEW
20   STOP
21   END
```

FIROT Program

```
01 ◆ LBL "FIROT"
02   FIX 1
03 ◆ LBL A
04   ADV
05   "AGE="
06   PROMPT
07   ARCL X
08   AVIEW
09   LN
10   1.8219
11   *
12   10.4222
13   —
14   "%WND="
15   PROMPT
16   ARCL X
17   AVIEW
18   LN
19   .8386
20   *
21   +
22   "N=0, S=1"
23   PROMPT
24   .4151
25   *
26   —
27   E↑X
28   "%DECAY="
29   ARCL X
30   AVIEW
31   END
```

[1] Trade or proprietary names are included for information purposes only and do not imply any endorsement by the USDA Forest Service.